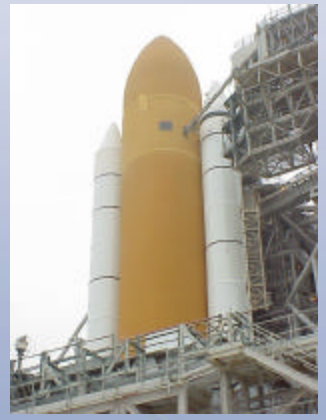
Idaho National Engineering and Environmental Laboratory

SAPHIRE Use at NASA

Marty Sattison



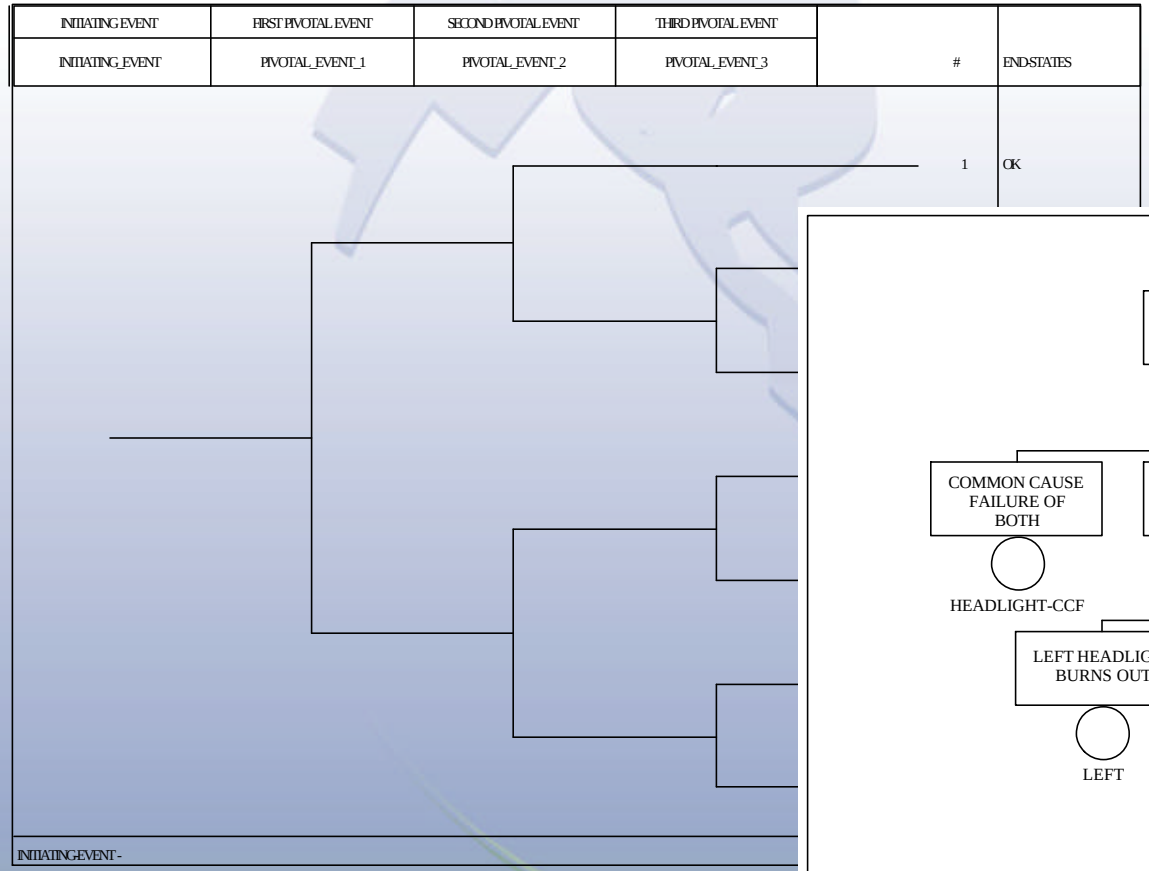
April 10, 2003

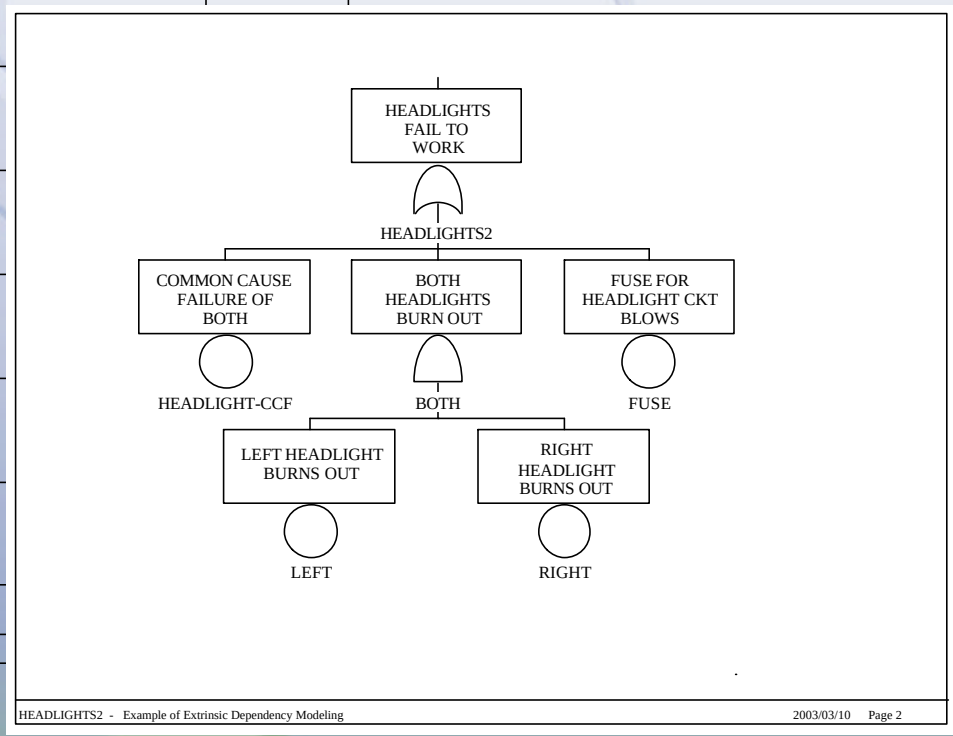
Systems Analysis Programs for Hands-on Integrated Reliability Evaluations

What Does SAPHIRE Do?

- *Tool for Creating/Processing Boolean Logic Models of Complex Systems to Estimate Reliability or Risk*
  - *Event Trees*
  - *Fault Trees*
- *Determine Frequencies of Accident Scenarios*
- *Identify Vulnerabilities in Design/Operation*

Event Trees and Fault Trees





NASA Use of SAPHIRE

- ***Galileo and Cassini Space Missions – Evaluation of Risk from Nuclear Payloads***

International Space Station Probabilistic Risk Assessment (PRA)

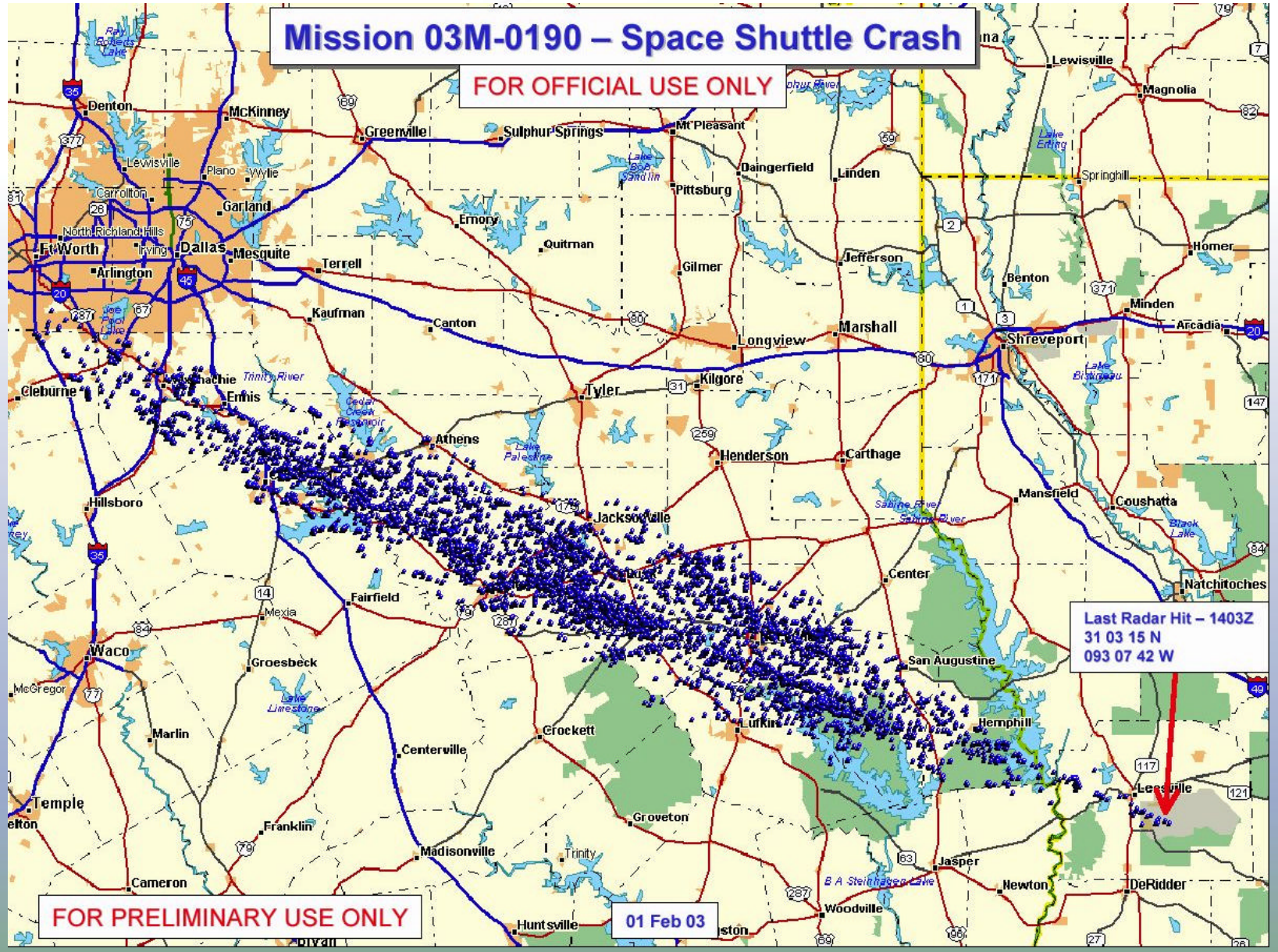
Space Shuttle PRA

Columbia Accident Investigation

- ***Accident Scenario: Feb 1, 2003 – Day 32***
  - ***6:44am MST – Re-Entry Interface, 400K ft, Mach 24.57***
  - ***6:49:32 – Initial Roll, Mach 24.51***
  - ***6:50:00 – 5 Events of Unexpected Comms Drop-out***
  - ***6:50:53 – Start of Peak Heating***
  - ***6:51:19 – Remote Sensors Indicate First Off-Normal Event (236.8K ft, Mach 23.6)***
  - ***6:51:46 – Inertial Sideslip Goes and Stays Negative Until LOS***
  - ***6:52:17 – Start of Off-normal Temp Trend on Brake Line in Wheel Well***
  - ***6:53:44 – First Report of Debris Leaving Orbiter***
  - ***6:54:07 – Fifth Report of Debris Leaving Orbiter***
  - ***6:54:35 – Large Bright Flash – Noticeable Luminescence in Plasma Trail***
  - ***6:55:32 – Crossing Nevada/Utah Border, 223.4K ft, Mach 21.8***

Columbia Accident Investigation

- ***Accident Scenario: Continued***
  - ***6:55:45 – 12th Report of Debris, Preceded and Followed by 2nd Plasma Trail***
  - ***6:56:16 – Rapid Temp Rises in Wheel Well Temp Instruments***
  - ***6:56:24 – First Indication of Instrument Damage – Wing Skin Temp Goes Off-Scale Low***
  - ***6:56:30 – Roll Reversal Initiated, 219K ft, Mach 20.9***
  - ***6:56:55 – Roll Reversal Completed, Mach 20.76***
  - ***6:57:53-59 – 2 Flares of Orbiter Shape Observed Over NM***
  - ***6:58:03 – Start of "Sharp" Aileron Increase – Roll and Yaw Increases***
  - ***6:58:20 – Altitude 209.8K ft, Mach 19.5, Crossing NM/TX Border***
  - ***6:59:32 – Loss of Signal, Nothing More Heard From Columbia***
    - ***Working: APUs, MPS, Fuel Cells, ME's, ECCLS, Body Flap, Right Wing***
    - ***Failed: All Hydraulics, Left Elevon, Left OMS***
  - ***7:00:21 – Main Body Breakup***


Mission 03M-0190 – Space Shuttle Crash
FOR OFFICIAL USE ONLY
Last Radar Hit – 1403Z
31 03 15 N
093 07 42 W
01 Feb 03
FOR PRELIMINARY USE ONLY
Denton
McKinney
Greenville
Sulphur Springs
Mt Pleasant
Lewisville
Plano
Wylie
Carrollton
Garland
Dallas
Ft Worth
Arlington
Mesquite
Terrell
Kaufman
Canton
Quitman
Emory
Pittsburg
Daingerfield
Linden
Gilmer
Jefferson
Longview
Marshall
Shreveport
Benton
Homer
Minden
Arcadia
Springhill
Lewisville
Magnolia
Cleburne
Ennis
Tyler
Kilgore
Athens
Henderson
Carthage
Hillsboro
Jacksonville
Mansfield
Coushatta
Natchitoches
Center
Fairfield
Mexia
Waco
Groesbeck
McGregor
Marlin
Centerville
Crockett
Lufkin
Hemphill
San Augustine
Temple
Franklin
Madisonville
Groveton
Trinity
Jasper
Newton
DeRidder
Woodville
Cameron
Huntsville

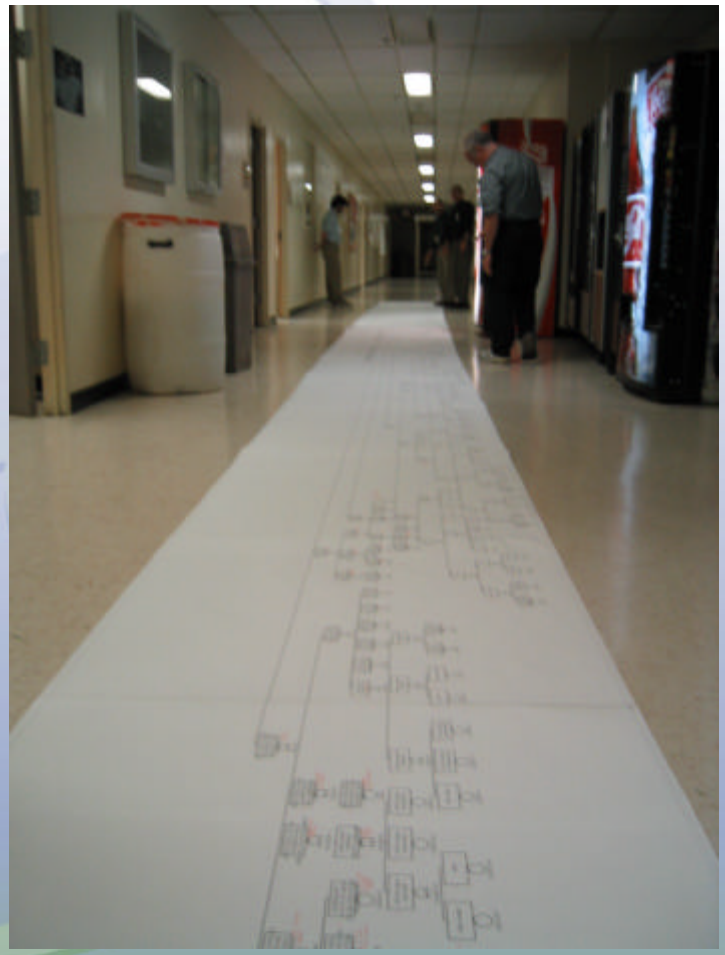
01 04 2003

CAI Support

- *Johnson Space Center Staff Organizes*
- *Investigation Team Consists of:*
  - *Mission Evaluation Room & Support Team (Engineers)*
  - *Risk Analysts*
  - *Contractor Support (Boeing, Thiokol, etc.)*
- *Shuttle PRA Lead Named Head Modeler*
- *INEEL Called In to Support Modeling Efforts*

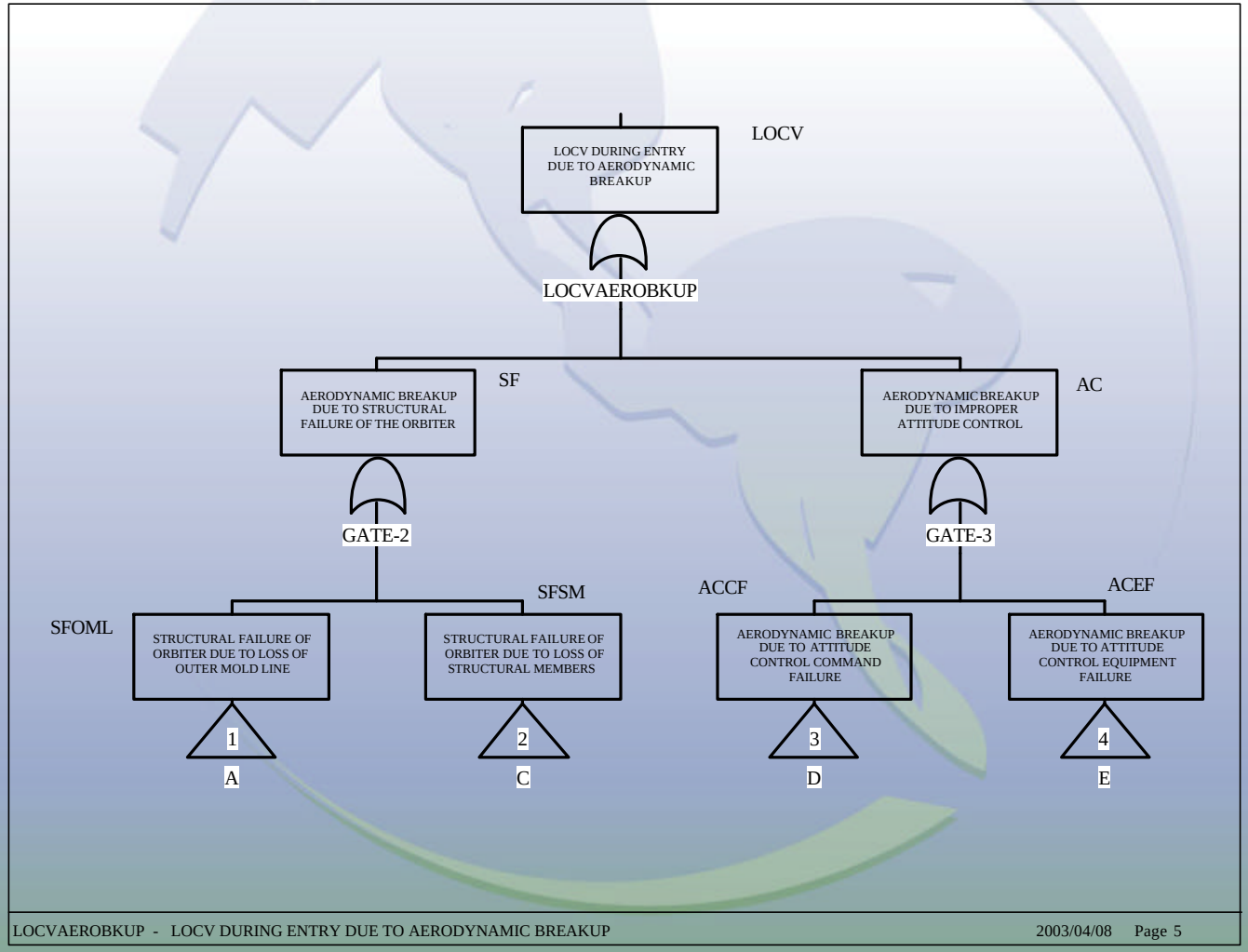
CAI Master Logic Diagram

- ***MLD Provides Roadmap and Tracking System for Investigation Activities***
- ***Top Event: LOCV During Entry Due to Aerodynamic Breakup***
- ***Next Level: Structural Failures & Improper Attitude Control***



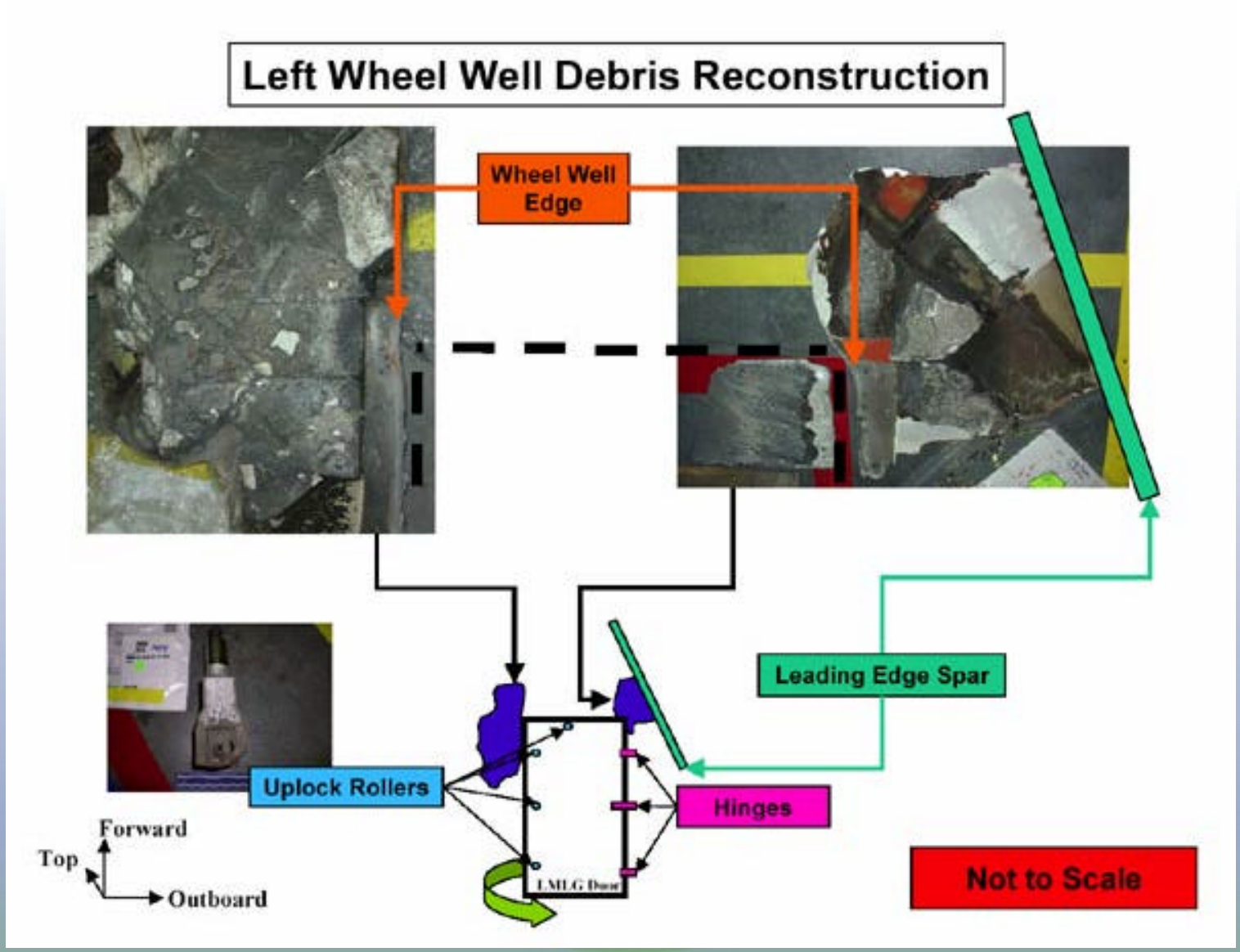
War Room Display

MLD Levels 1 - 3



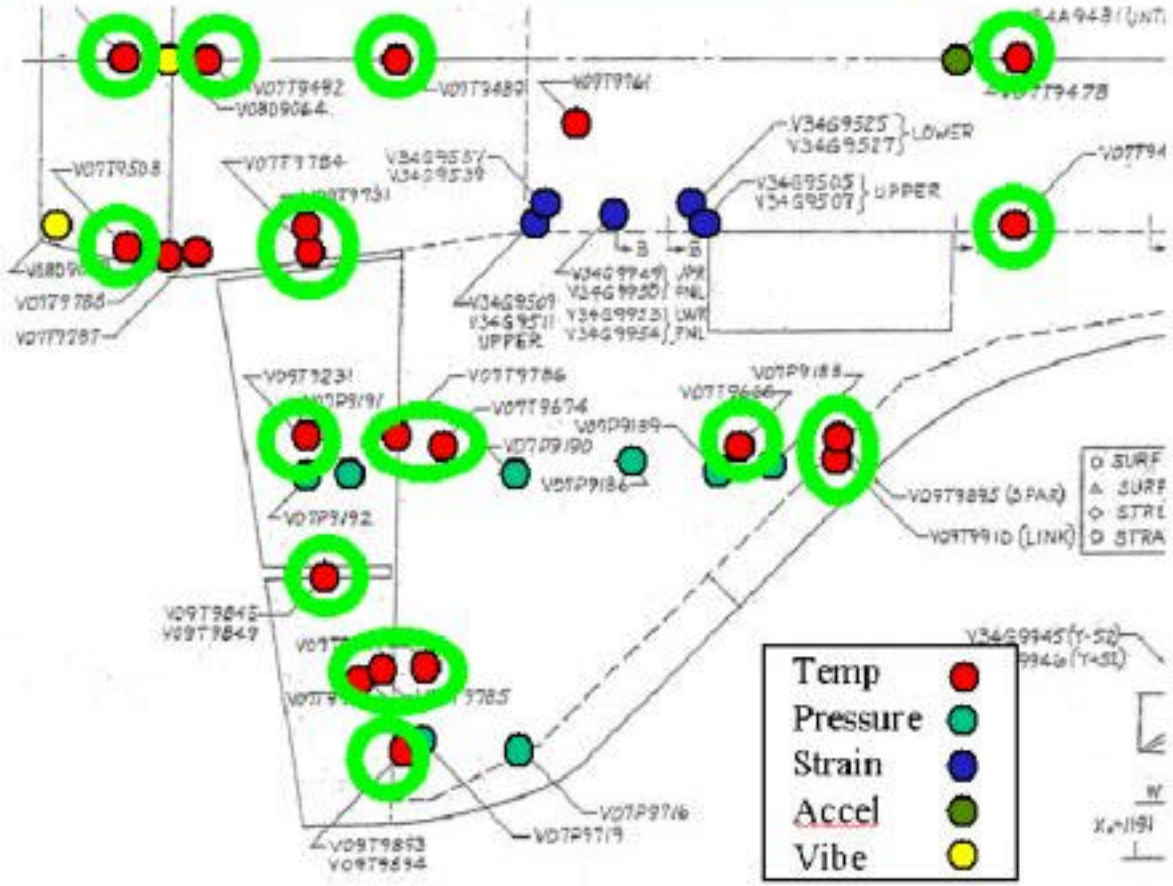
MLD & Work Breakdown Structure

- *Every Element of MLD Given a WBS Number*
- *Top Levels Given Distinct Names:*
  - *LOCV*
    - *SF*
      - *SFOML*
        - *SFOML-WING*
        - *SFOML-CABIN*
      - *SFSM*
    - *AC*
      - *ACCF*
      - *ACEF*


Left Wheel Well Debris Reconstruction
Wheel Well Edge
Leading Edge Spar
Uplock Rollers
Hinges
Forward
Top
Outboard
LMLG Door
Not to Scale

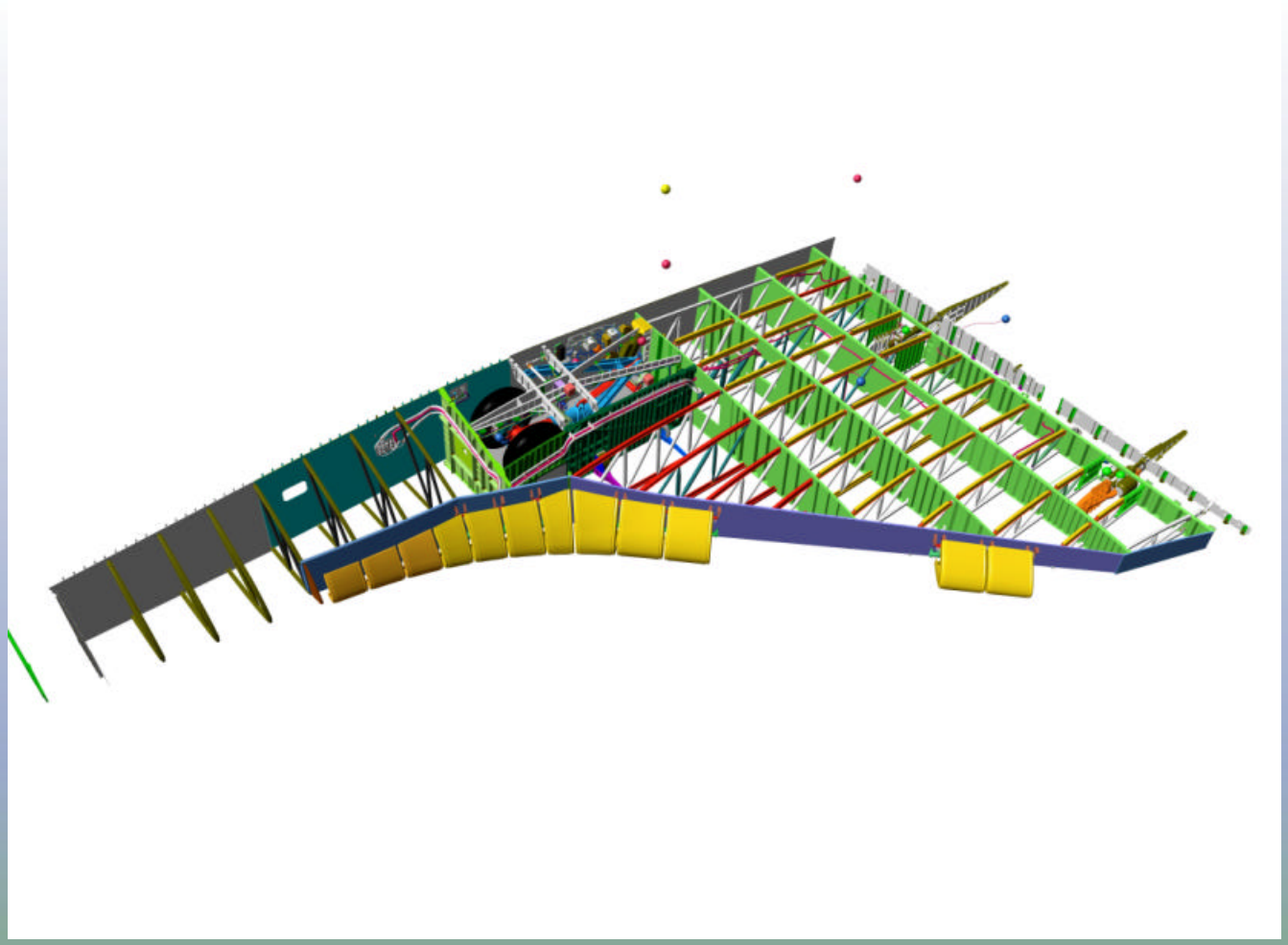
Left Wing Temperature Measurements

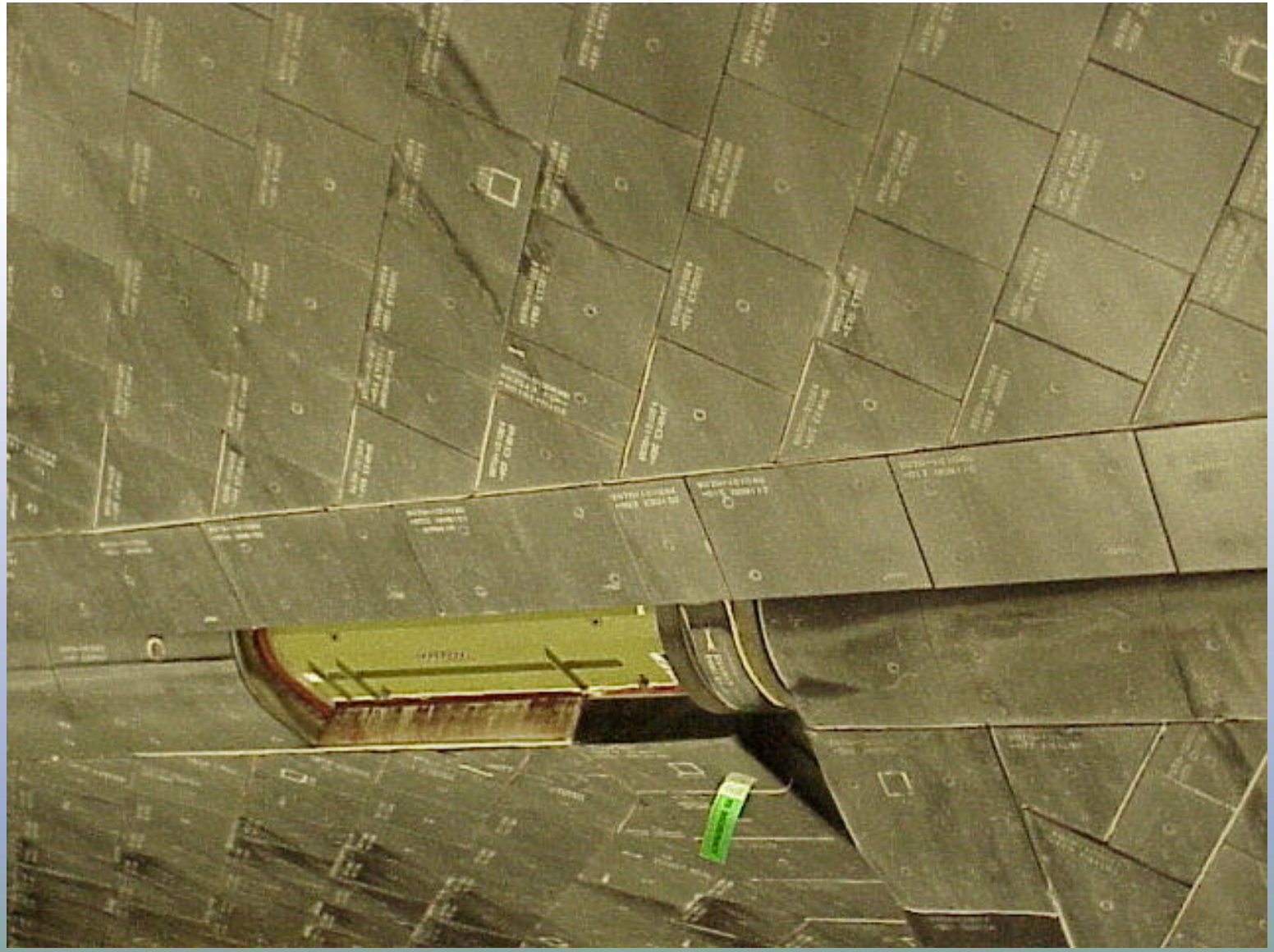
PRELIMINARY – UNDER REVISION



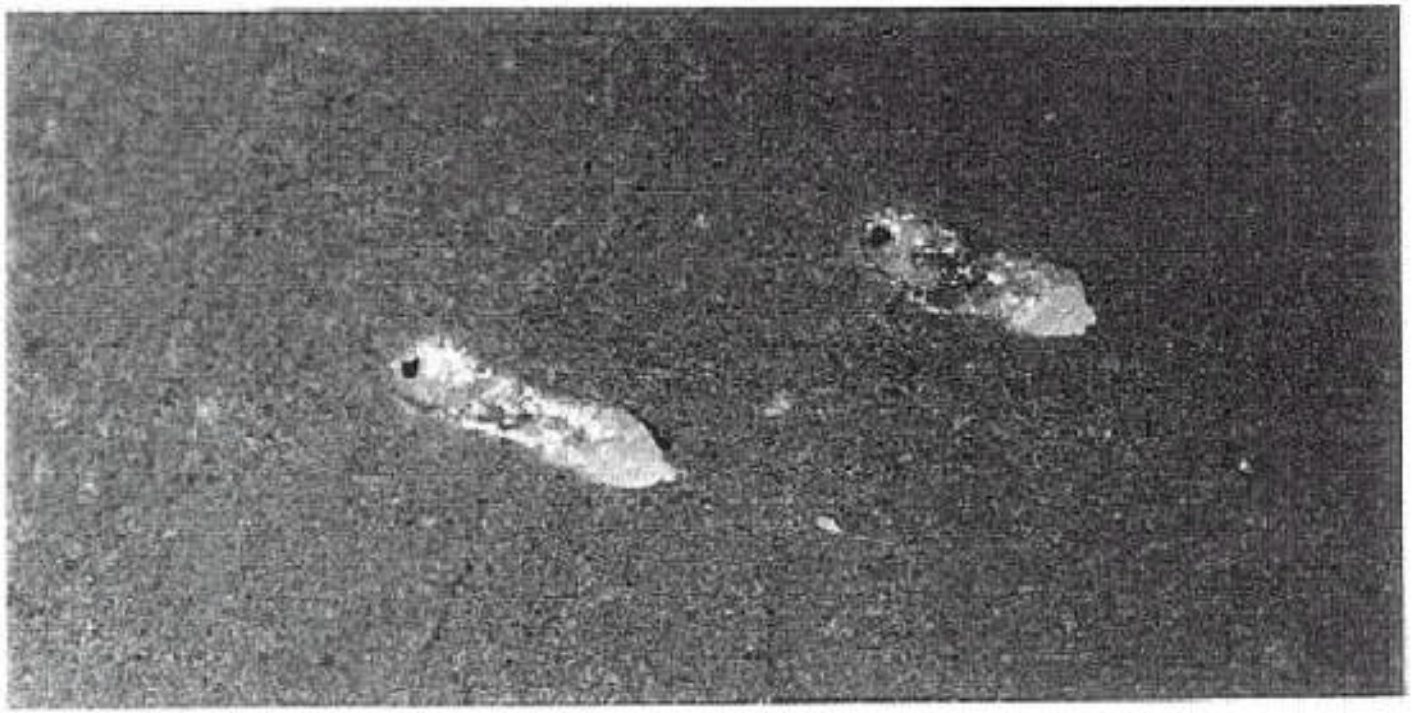
OEX Recorder, Top Cover Removed

Concentrated on Left Wing



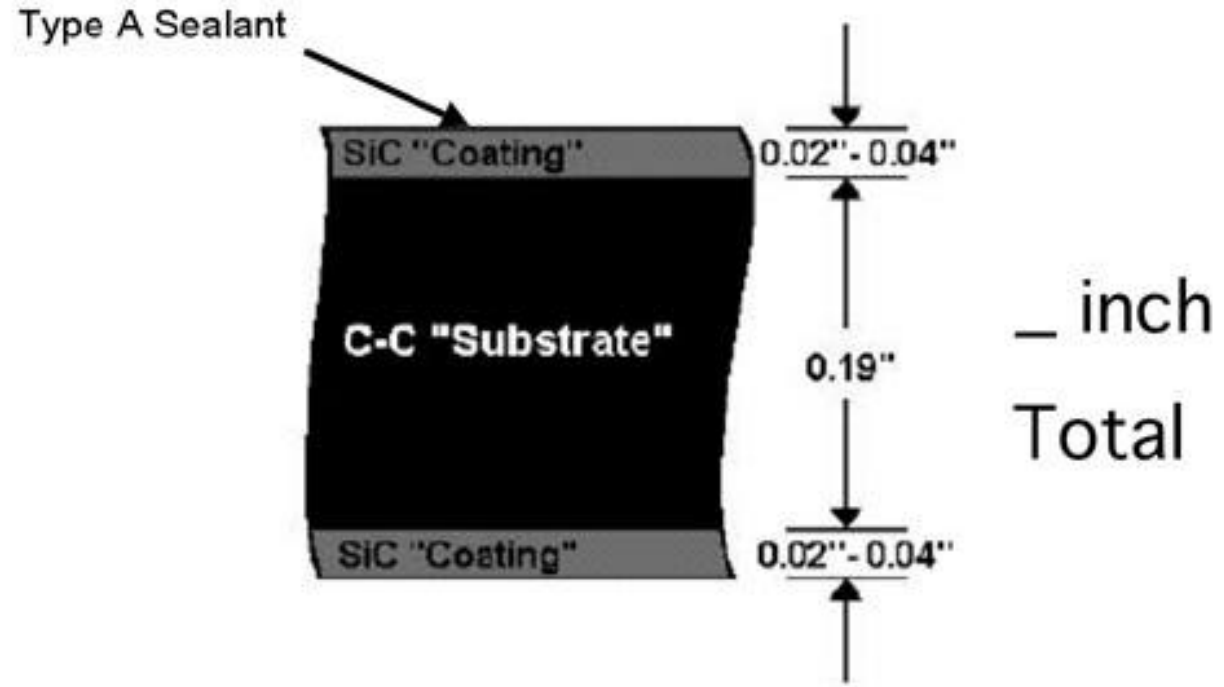


Reinforced Carbon Carbon - Pinholes



Typical Pinholes - First Discovered on OV-102-12 in 1992

Typical RCC Configuration



Type A Sealant– "Help Protect the Carbon"

Silicon Carbide Coating – "Protect the Carbon"

Carbon-Carbon Substrate – "Carry the Load"

Reinforced Carbon Carbon - Pinholes

- Pinholes first discovered on OV-102 after 12 flights in 1992
- Pinholes found on **all** orbiters
- Pinholes increased with flight exposure
  - Total as high as **20 to 40 per panel** over time
- Potential **root cause** of pinholes :
  - Zinc leached out of Rotating Service Structure **paint primer**
    - Pad Topcoat not refurbished—more primer exposed
    - Rain washes zinc oxide onto Orbiter
  - Zinc combined with Silicon and Oxygen during re-entry to form **pinholes**

Launch Pad – Potential Zinc Source

EXPEDITION 6
INTERNATIONAL SPACE STATION
Don Pettit
Ken Bowersox
Commander
Nikolay Budarin
NASA